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PAPUA NEW GUINEA: A CENTRE OF GENETIC DIVERSITY IN WINGED BEAN (*PSOPHOCARPUS TETRAGONOLOGUS* (L.) DC.)

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INDEX WORDS

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SUMMARY

The results of an exploration and collection work on *Psophocarpus tetragonolobus* (L.) DC. are presented. A wealth of genetic diversity in the Highlands of Papua New Guinea was uncovered, and experimental work resulted in isolation of 121 pure lines as the first germplasm collection. It is believed that it may not be indigenous to Papua New Guinea but that it has been introduced to this Island long before the first European contact. The implications of the finding for the development of this species in present and in future it discussed.

INTRODUCTION

The general statement that Papua New Guinea (PNG) lies in the hot wet tropics, (FORD, 1973), hardly befits the variation in climatic conditions caused by extensive areas of the Highlands, ranging between 1000–4000 m. The fertile valleys of the Highlands (Fig. 1) have a dense population, which subsists on a variety of crops. These include sweet potato (*Ipomoea batatas* (L) LAM.) as a main staple, taro (*Colocasia esculenta* (L) SCHOTT), yam (*Dioscorea alata* L.), banana (*Musa* sp.) and cassava (*Manihot esculenta* CRANTZ.) being next in importance. A major leguminous crop grown traditionally is winged bean (*Psophocarpus tetragonolobus* (L) DC.). Of this legume, seeds, tubers, leaves and flowers are eaten. A limited amount of winged bean is also grown in parts of the Sepik Provinces, where beans are the more favourite edible part. Cultivation is now extending in low lying regions because of the migration of the Highlanders. Owing to the equatorial climate of PNG this crop can be grown throughout the year but in the Highlands the main season is between June-December.

The Highlands of PNG have been identified as areas of severe protein deficiency (KORTE, 1974). This led to an active research interest in this locally accepted legume, which is widely grown but whose overall contribution to the diet is relatively small. All parts of the plant are rich in protein, and MASEFIELD (1973) attributed this to the

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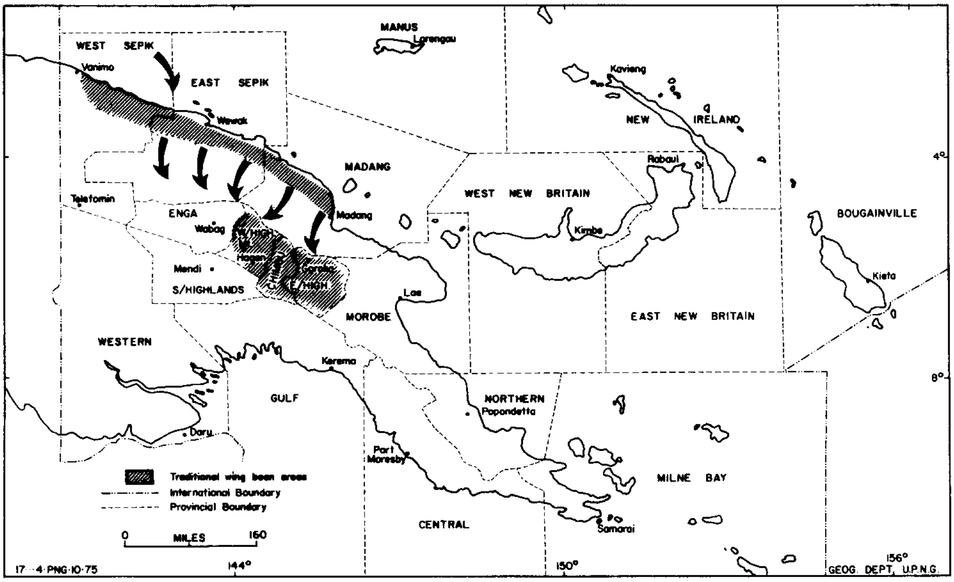

Fig. 1. Traditional winged bean growing areas of Papua New Guinea. Arrows show the possible route of introduction of winged bean.

abundant nodulation and consequent high rate of nitrogen fixation. The seed protein content and oil content have been reported to range from 30–37 and from 15–18 percent respectively (MASEFIELD, 1973; POSPISIL et al., 1971; KHAN & CLAYDON, 1975).

In view of its nutritional value and the need to expand legume production and consumption in the PNG Highlands, a programme on the Improvement of winged bean was started at the University of Papua New Guinea in 1973. At the same time there was a world-wide interest in this crop. MASEFIELD (1973) reviewed the scant and scattered information on the species and projected its potential. The US National Academy of Sciences responded to this by appointing a panel of twelve international scientists, who met in October, 1974. As a result, a campaign was started to promote research (ANON, 1975). Priority was placed on the exploration and conservation of the available genetic variation. an undertaking which was already in progress at the University of Papua New Guinea.

This paper therefore reports the genetic evaluation of winged bean in PNG and the building of the world's first germplasm collection of this species together with the implications for breeding.

MATERIALS AND METHODS

Collection and exploration was started in 1973, when the author visited the winged bean growing areas of the Highlands and Sepik provinces (Fig. 1) and collected bulk samples there. His collection was supplemented by samples from students and Dr J.

Powell, which resulted in a total of 18 bulk samples representing various areas. There was considerable variation in seed colour and this criterion was therefore used to sub-divide the samples into 118 location $\times$ seed colour lines. These lines were grown in separate rows of 6m in February 1974. The planting distance within rows was 1 m. Germination in some lines was very poor, which may have been due to prolonged storage prior to collection. A population of 700 plants was thus established. A number of plants died from an unidentified root disease and some did not set seeds. Data on flowering were not properly recorded as most lines were heterogenous at this stage. Records on morphological characters were taken as new variations were discovered, such as variations in flower colour, stem colour, pod colour, pod shape (as seen in cross section) and pod surface. Post harvest data included seed colour, mean seed weight (based on a sample of 20 seeds), grain yield and tuber yield.

Single plant selections were made on the basis of the above data to establish a germplasm collection. It was assumed that morphologically identical variants from different locations were genetically different. Also, within a location single plants differing in morphological characters were selected for growing in the following season.

In July 1974, 180 plant progenies of selected plants were grown in 4 m long rows. The distance between rows was 1 m, but plant to plant distance was now reduced to 50 cm. Since there is virtually no rain in Port Moresby during this season, plots were regularly irrigated. Several plants were found to be infected with root knot nematode (*Meloidogyne* sp.). All progeny rows appeared to be homogeneous with respect to qualitative characters. Duplicates from within locations were discarded at this stage except for those mean seed yield of which per plant was more than 20 g. This step was taken to increase the number of high seed-yielding lines in the germplasm. Eventually a germplasm collection of 121 pure lines was established. All qualitative and quantitative data recorded in the initial screening were also recorded during this season. In addition, growth vigour was recorded subjectively on a scale of 1–5, with 5 referring to vigorous lines comparable to the general growth vigour of *Lablab niger* MEDIK. and shelling percentage was calculated as (seed weight/pod weight) 100.

Experimental plots were situated in Waigani Valley (9°25′S lat., 147°8′E long.) at Port Moresby. N, P and K were each applied at a rate of 50 kg per ha, and when plants were 1 month old they were sprayed with Hortico's Complete Nutrient Mixture Aquasol to correct any possible micronutrient deficiency.

RESULTS

Chromosome number. From meiotic observations the chromosome number in this species was reported by Ramirez (1960) to be $n = 13$. Dr R. D. Brock of CSIRO, Canberra has made extensive chromosome counts on both metaphase and meiotic late prophase and has found the chromosome number in PNG material to be $n = 9$ (Fig. 2 and 3) which confirms TIXIER's (1965) finding.

Initial screening. Considerable variation in growth habit was observed in the population of 700 plants. It ranged from slow growth and small stature to massive cover as in *Lablab niger* MEDIK. and vigourous indeterminate varieties of *Vigna unguiculata*

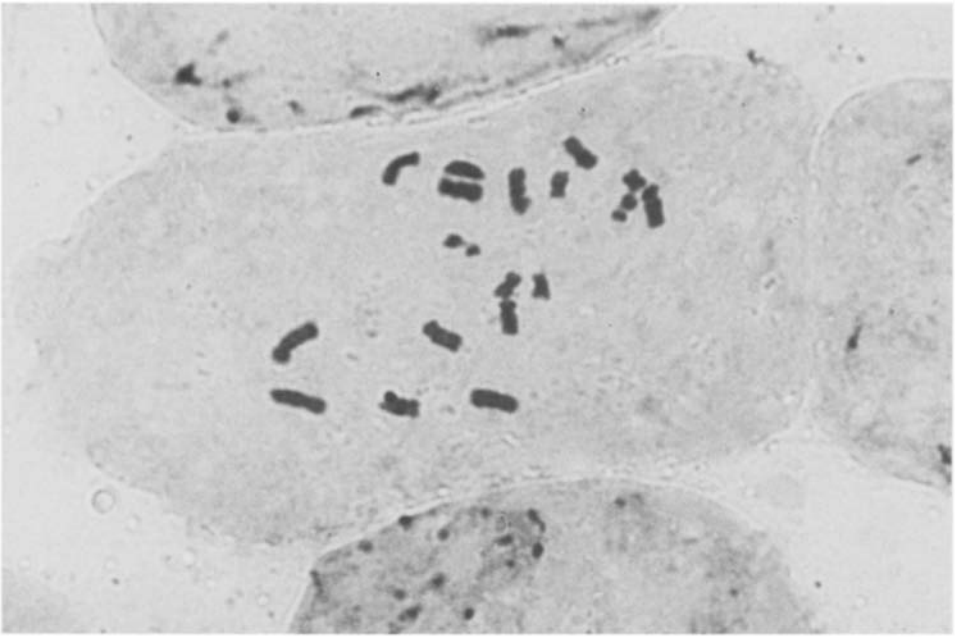

Fig. 2. Root tip cell of UPS 52 with 2n = 18 × 2000. (Courtesy : Brock).

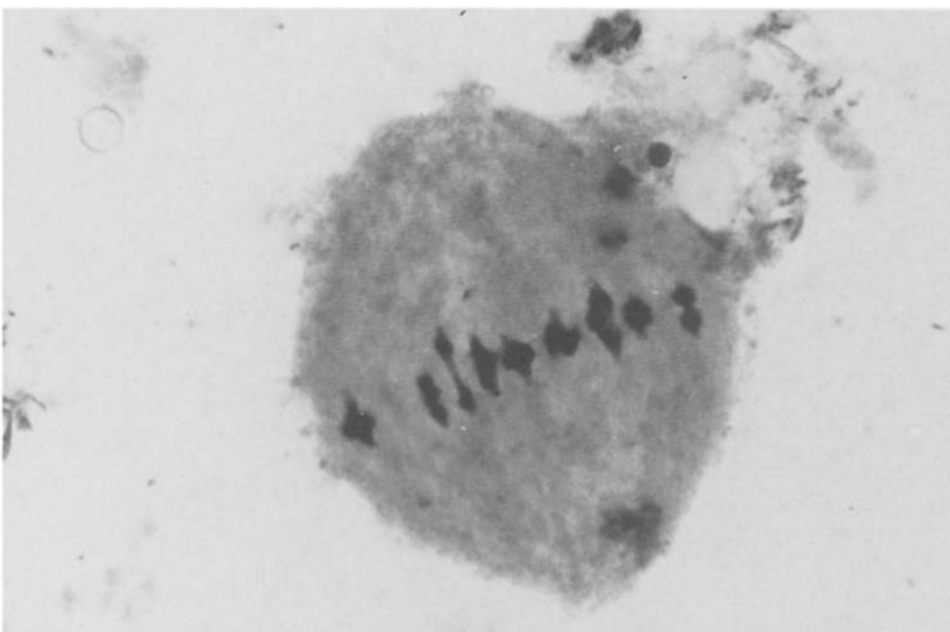

Fig. 3. Pollen mother cell of UPS 31 with 9 bivalents. × 1370. (Courtesy : Brock).

(L) WALP. However, determinate growth habit was not observed. Flowering occurred between 48–90 days after planting and most of the plants produced mature dry seed in 3–5 months. Flowers opened after mid-day, which is in contrast to the situation in Ghana, where they open between 8.00–10.00 h (POSPISIL et al., 1971). About 40 lines in the experimental plot were derived from a single plant. None of these progenies showed any segregation for qualitative characteristics or for general growth characteristics, indicating that their parents were homozygous. This may support a hypothesis that under PNG conditions winged bean is predominantly self-fertilized. Although there had been no inoculation with *Rhizobium*, abundant nodulation was observed in most plants.

The variation observed in qualitative characters is shown in Fig. 4. The basic pigmentation of the stem was purple and green, with green being most common. Variation in purple stem extended from purple tinge on green background to deep purple colouration.

The two basic flower colours are blue and purple, with blue colouration being a little more prevalent. Considerable variation within the above colours was observed with respect to the intensity. A few plants had almost white flowers. This, however, is regarded as an extreme variation of light blue as in some cases both light blue and almost white flowers were found on the same plant. In many varieties the stigma protrudes through the keel before anthesis. This characteristic makes it ideally suited for cross pollination. However, from the earlier discussion it would appear that the above mechanism is not utilized for cross pollination in PNG, presumably due to the scarcity of suitable pollinating insects.

There are three background colours in pods: green, pink and pale yellow. On the green background there were often purple spots extending to varying degrees, and in certain cases pods can be defined essentially as purple. In the more common variation the wings on a green pod displayed light to deep purple colouration. With the pink background there were two variations: (i) wings displaying purple colouration and (ii) wings displaying a mixture of green and purple shades. All pods with pale yellow background displayed green-purple wings. Curiously, pink and pale background pods were associated with small pod size, short stature of plant, thin stem and small leaves.

Pod shape can be classified as rectangular semi-flat, flat on sides, and flat on suture (Fig. 5). However, more than 90% of the pods showed a rectangular shape. In most rectangular podded varieties, when pods dry out at maturity the wings collapse and the dry pod flattens.

The pod surface could be classified into rough and smooth, with rough podded ones being more numerous. Considerable variation was observed in the roughness of pods but an attempt has been made to make only two subclasses i.e. rough and semi-rough.

The seed colour which was used to classify the original seed samples was found to be a relatively variable character. There appear to be two basic colours – brown and tan. Brown seeds may vary in intensity from light brown to dark brown, and they often have a dark ring around the hilum. Such rings or bands may vary in width and may sometimes extend half-way arôund the seed. Dark specks were also seen on seeds in some plants.

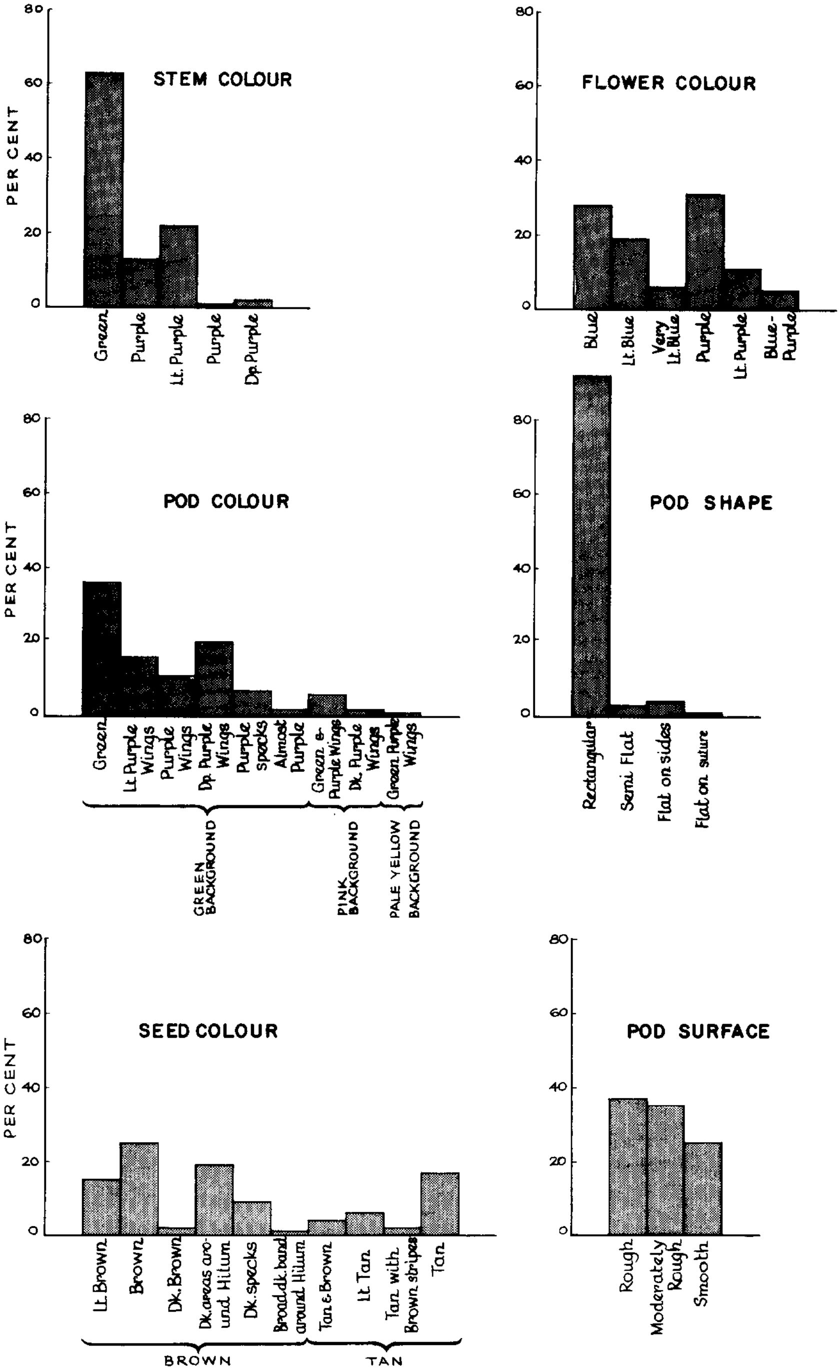

Fig. 4. Variation in qualitative characters.

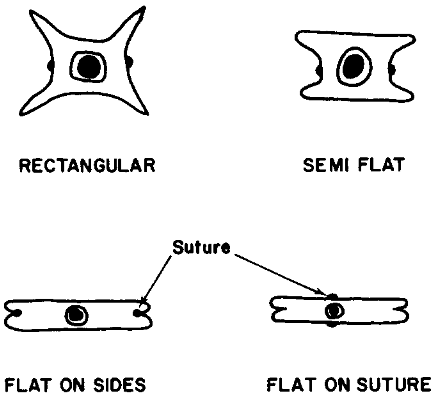

Fig. 5. Diagramatic representation of pod shape as seen in cross section.

The plants with variations of tan were less numerous. Some of the variations in seed colour observed amongst the original seed lot did not appear in the progeny. This was particularly noticeable with white specks on seeds, indicating the importance of environment in affecting seed colour.

The coeffient of variation among quantitative characters ranged from 30 % in mean seed weight, and mean pod length to 83 % in seed yield per plant (Table 1). It should be noted that for pod length a mean of 5 pods has been used to represent a plant and in seed weight mean seed weight has been calculated by weighing 20 seeds from each plant. An interesting point is that our mean pod length is less than the shortest pod reported by POSPISIL et al. (1971). However, it is likely that POSPISIL's data were based on a narrow gene pool consisting of mainly long podded varieties.

Leaf-size (area of all leaflets in a leaf) also showed considerable variation. Occasionally tetrafoliate and pentafoliate leaves were found among normal trifoliate leaves on the same plant.

Seed yield per plant varied between 0.60–72 g. But, a heavy infestation of *Maruca testulalis* GEYER had been observed which resulted in considerable dropping of flowers. The above range may therefore be regarded as an underestimate of the yield potential. The yield projections made at this stage of the work have not been realized as yet but are presented here as a matter of historical interest. The estimated potential seed yield of best plant progeny at 1 × 1 m spacing would therefore be 720 kg/ha. This is considerably higher than 570 kg/ha reported by POSPISIL et al. (1971) at a spacing of 0.61 × 0.61 m. To our mind it should be possible to use 0.61 × 0.61 m spacing without any reduction in yield per plant. A potential yield of 1946 kg/ha is thus projected.

Only 16 % of the plants produced tubers. The highest tuber yielding plant gave a yield of 50.3 g, projecting the potential yield at the spacing of 0.61 × 0.61 m to be 1350 kg/ha. The average seed yield of tuber producing plants was 9.56 g which was considerably below the overall average (15.2 g). However, 27 % of the tuber producing line were found to give a seed yield which was above average, indicating the possibility of selection for both tuber production and seed production simultaneously.

The best dual purpose plant gave a tuber yield of 16.7 g and a seed yield of 55 g. Again assuming a spacing of 0.61 × 0.61 m, it was estimated that a potential yield of

450 kg/ha of tuber and 1485 kg/ha of seed from a dual purpose crop is possible. Using an average moisture content of 60% for tubers and of 11% for seed, the estimated potential edible dry matter yield will be 1322 kg/ha.

Study of the germplasm collection. As expected, the majority of lines exhibited an intermediate vegetative vigour (= 3). The poor vigour in some cases was associated with the infestation of nematodes. Only 5% of the lines showed a vigour of 4 or higher. The majority of lines (61%) had green stems while the remainder had various shades of purple. Five percent of the lines were classified as having pink stems, but it is quite likely that such is a mere variation of the purple shade. The blue flowered and purple flowered lines were equally represented, and a small percentage of lines (2.48%) exhibited a flower colour which can at best be classified as intermediate between purple and blue. The observations during this generation confirmed the earlier belief that white colour is an environmental variation, and that such flowers may occur side by side with the light blue flowers on the same plant.

Amongst pod characteristics, green as background was the most common colour with more than half of these lines showing purple shades and purple margins on wings. Other variations described earlier were less numerous. Most of the pods were rectangular in cross section (91.35%). Among flat pods, 18% were flat on sides and only 1.6% on sutures. Eighty percent of the lines had a smooth pod surface and the rest exhibited varying degrees of roughness.

Brown-seeded lines appeared to be the most abundant. These brown-seeded lines showed a great deal of variation in markings. Similarly, a limited amount of variation was also observed within tan-seeded lines. A few lines have the seed colour which is intermediate between dark brown and tan and they are referred as Dark Brown/Light Tan (DB/LT).

The quantitative parameters of the germplasm collection are shown in Table 1, and are based on an average of seven plants for each pure line. There is a small increase in the seed yield per plant, which may be due to the inclusion of all the lines with mean seed yield per plant of greater than 20 g. This is associated with a similar increase in seed size. KHAN & CLAYDON (1975) emphasized that the low shelling percentage may be an important factor in limiting the seed yield. The available data showed the range in shelling percentage to be 9–65, with a mean of 41.8 ± 1.02. The very low values of shelling percentage are generally associated with the infestation of pod borers. However, data clearly show the possibility of selecting for high shelling percentage.

A correlation matrix for five characters including seed yield per plant, pod length, number of seeds per pod, seed weight and shelling percentage is presented in Table 2. The data were obtained from the germplasm study and degrees of freedom are 94. The seed yield in a plant was found to be significantly correlated with number of seeds per pod ($P<0.001$) and the shelling percentage ($P<0.05$). Number of seeds per pod exhibited a positive correlation with seed weight ($P<0.001$). The strongest correlation was found between pod lenth and seed weight ($P<0.001$).

The data on the 10 best yielding lines are shown in Table 3. The best yielding line has a high shelling percentage, and above average seed weight and number of seeds per pod. However, the mean pod length is marginally lower than the population mean.

Table 1. Variation in quantitative chracters in the original population and in lines of the germplasm collection.

Characters	Original population				Germplasm collection (121 lines)		
	number of plants studied	range	mean	coefficient of variation (%)	range	mean	coefficient of variation (%)
Single leaf area (cm^2)	637	19–459	178 ± 3.8	54	–	–	–
Mean pod length (cm)	541	5.8–26.4	15.2 ± 0.2	30	9.1–23.4	14.6 ± 0.61	44
Number of seeds/pod	–	–	–	–	3.0–17.3	9.4 ± 0.23	27
Mean seed weight (mg)	492	62–417	224 ± 3.0	30	110–449	241 ± 0.01	21
Seed yield per plant (g)	471	0.6–72.0	15.7 ± 0.6	83	0.9–51.5	16.0 ± 1.0	68
Shelling percentage	–	–	–	–	9–65	41.8 ± 1.0	25
Tuber yield per plant (g)[1]	111	1.3–50.3	15.9 ± 1.1	72	–	–	–

[1] Only tuber producing plants were included in estimation of statitical parameters.

Table 2. Correlation matrix for 5 characters in winged bean.

	Pod length	Number of seeds per pod	Shelling percentage	Seed yield
20 Seed weight	+0.586***	+0.241*	−0.119	+0.017
Pod length		+0.576*	−0.193	−0.089
Number of seeds per pod			+1.191	+0.417***
Shelling percentage				+0.221*

Parent/offspring data and heritability of various characters. The comparison of parental characteristics with those of offspring gave an opportunity to learn about the heritability of various characters. The word heritability has been here in its literal meaning (Collins English Gem Dictionary, 1972), and does not refer to the statistical parameter h^2.

In stem colour, all the plants bred true to type, although there was some disagrrement in the degree of purple colouration.

As for flower colour, ninety percent of the plants with light blue flowers bred true, only ten percent progenies were classified as blue. Of the plants with blue flowers 81 per cent bred true and the rest gave rise to the progenies which were classified as light blue. The purple flowered and light purple flowered plants also bred true except in three cases. The reasons for this discrepancy can not be explained. In general, flower colour appears to be a highly heritable character and even the shades of the two colours show a high degree of heritability.

Pod colour and pod shape were also inherited to type, however, there was a grat deal of discrepancy in roughness of pod surface when compared with the parents. Further controlled experiments are needed to study the inheritance of this character.

As for quantitative characters, data on parents and offspring were available for 3 characters, which included pod length, 20-seed weight and yield per plant. The correlation between parent and offspring was not significant for seed yield (0.19 N.S), but significant correlations were found for pod length (+0.58***) and 20-seed weight (+0.40***). The high heritability of pod length and 20-seed weight may be of potential importance in selection as both these characters are positively correlated with grain yield.

DISCUSSION

A wealth of genetic diversity has been revealed in the winged bean material of the Highlands of Papua New Guinea. This diversity is exhibited by differences in growth vigour, colours of stem, flower, pod and seed, pod shape and size, leaf-size, pod length, number of seeds per pod, seed yield, tuber yield and shelling percentage. Unfortunately, there are virtually no reports of a similar nature to enable comparison with other countries, but through extensive communications with overseas workers it appears that Papua New Guinea is the centre of greatest diversity at the present time. However, it is unlikely that winged bean oritginated in Papua New Guinea as no other wild or cultivated member of *Psophocarpus* genus is known to occur in Papua

Table 3. Characterstics of the ten best yielding lines in winged bean germplasm.

UPS[1] No.	Origin	Vegetative vigour[2]	Pod length (cm)	Number of seeds per pod	Seed weight (mg)	Shelling percentage	Yield per plant (g)	Estimated (kg/ha)
34	Western Highlands	3	14.0	6.8	295	36	38.4	768
45	Kindeng (Chimbu)	3	15.5	10.7	217	53	38.0	760
46	Kindeng (Chimbu)	3	11.8	9.2	220	45	33.5	670
57	Kindeng (Hagen)	3+	11.0	9.3	188	–	43.9	878
61	Kindeng (Wabag)	3	13.8	9.9	235	52	35.3	706
62	Kindeng (Hagen)	3+	14.3	10.8	255	52	51.5	1030
72	Kondepana	4	18.6	14.8	257	48	34.7	694
78	Kamaliki	3	10.1	6.9	217	48	38.7	774
87	Matuasa	2+	10.0	6.4	243	41	36.1	722
111	Aiyura	3	12.0	9.1	225	77	38.7	774

[1] UPS refers to University Accession numbers of *Psophocarpus*.
[2] Vegetative vigour was scored subjectively on a scale 1–5, 1 being the least vigorous line.
[3] Kg/ha yield estimates are based on a plant population of 20000 plants/ha, the actual planting density of the experiment.

New Guinea. BURKILL (1906) believed it to have originated in Mauritius, Madagascar or the East Coast of Africa. A related species *Psophocarpus palustris* DESV. is distributed widely in Africa both under cultivation and in the wild, where other remaining members of the genus *Psophocarpus* are also found (MASFIELD, 1973). On linguistic grounds, BURKILL (1906) believed that this species was introduced to South East Asia by Arab traders during the 17th century, and POWELL (1974) suggested that it may have reached Papua New Guinea at almost the sametime. The traditional winged been areas in the lowlands are confined to the Sepik provinces, which are in close proximity to the Indonesian Archipelago. It is therefore logical to assume that it may have first reached the Sepik provinces. Its movement from the lowlands of the Sepik provinces to the valleys of the Central and Western Highlands may have occurred through the neolithic trade system. HUGHES (1973) provided evidence of trade in valuable shells and artifacts between the Northern Lowlands and the Central Highlands of Papua New Guinea before European contact, and showed that live animals and plant materials including oil *Pandanus* were also traded.

The history of a well developed agriculture in The Highlands dates back more than 6000 years (POWELL et al., 1975), and the introduction of sweet potato, the most important staple crop, is now regarded to have taken place 1200 years ago in contrast to the earlier belief that sweet potato came to New Guinea only 400 years ago through Portuguese trades. If BURKILL's linguistic argument about the introduction of winged bean to South East Asia is disregarded, then it is likely that winged bean came to PNG earlier than the 17th century.

While the exact date of its reaching Papua New Guinea can be disputed, it is clear that winged bean must have been in the Highlands long before European contact to have evolved such amount of variation as revealed in this study. The variation may have evolved mainly through mutation as the extent of outcrossing in PNG appears to be very low. However, bees have been found to visit flowers occasionally and Dr. Marshall (personal communication) of CSIRO, Canberra has found some evidence of heterozygosity in natural populations through the study of enzyme systems. A limited role of recombination may thus be emphasized. The multiplicity of purposes for which this crop is grown must have prevented undue selection pressure, and may have resulted in the conservation of variation. ZOHARY (1970) discussed the role of mountainous topography in the evolution of genetic diversity. Variation in winged bean can not be solely due to rugged topography and the partial isolation of populations, since many different variants are found within the same plot in a farmer's field in PNG.

The variation occurring in PNG material will contribute greatly to the development of this crop for a protein hungry world. The present prospects are, however, limited to subsistence and semi-subsistence agriculture. Recombination amongst existing types through deliberate crossing should provide scope for further improvement. The aims of selection may change from an 'all purpose plant' to specific varieties bred for tuber production, seed production or for cover cropping as advances are made in agricultural technology. However, its large scale cultivation will be hindered by the indeterminate viny growth habit. An erect self-supporting variant, which at present is not known to occur, will make a major contribution to the extension of this species as a field crop. A mutation breeding programme financed jointly

by the International Atomic Energy Agency at Vienna and the University of Papua New Guinea is currently in progress to evolve such a mutant. Mutation breeding may also contribute to an alteration of the day length requirement of this species, which, coupled to its tolerance to low temperatures, may extend its horizons to temperate summers. An integrated research programme involving studies in physiology, genetics, agronomy and nutrition is in progress, and the results may help plant breeders to design recombination plans to create a variety which may become a rival to soyabean in the not very distant future.
We planned to publish a catalogue of the genetic material reported in this paper, and make the germplasm freely available on request.

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